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Water quality parameters assessment of Ras El-Ain Natural Ponds, Tyr, Lebanon

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ABSTRACT

Lebanon's natural water resources are facing serious problems related to quality and quantity. Unregulated resource planning and rising demand are the main factors. Water resources are used in several ways. However, due to the over-exploitation, and random use of surface water resources, Lebanon is facing severe problems related to water need and accessibility. This study focused on the Ras El-Ain area located in the South of Lebanon that dedicated, along with other reservoirs, to supply potable water for Tyr and the surrounding villages. Nowadays, the water of these natural ponds has been polluted significantly due to unrestricted liquid and solid waste disposal. Physicochemical and microbiological water characteristics, following the LIBNOR guidelines, of four selected samples from each natural pond were tested. In addition, another sample was taken from a water reservoir that collects water from these natural ponds. The obtained results were used to evaluate the extent of pollution in these natural ponds using PhreeQC software. The novelty of this study stems from the fact that it is the first to shed light on the degree of pollution level in the Ras El-Ain ponds, Lebanon (an unstudied area).

Key words: microbiological characterization, physicochemical characterization, pollution, Ras El-Ain ponds, surface water assessment

HIGHLIGHTS

- This topic discussed one of the major problems not only in Lebanon but also in every country.
- Assess the inappropriate conditions besides rivers, ponds, and basins.
- Mentioned the characteristics found in the Ras El-Ain natural ponds which affect in a direct way the environment and the people's health.

GRAPHICAL ABSTRACT

1. INTRODUCTION

Water quality is the essential element that affects fauna, flora, and human health. Nevertheless, water quality is often changed as it is exposed to natural factors (such as climate warming and soil erosion) or manmade factors and activities (like uncontrolled industrial wastes and wastewater discharge) (Barbieri *et al.* 2021). All these factors will lead to a variation in the quality and quantity of both surface water and groundwater. The variations in the freshwater quantity and quality (snow, surface water, and groundwater table) give crucial information for analyzing water resource shortfall at a local scale (Andrew *et al.* 2017).

Lebanon had an area of 10,452 km² and a coastline of 210 km from north to south. It is located along the eastern coast of the Mediterranean Sea. It is recognized that the water sector in Lebanon suffers from various technical and management constraints. Serious undesirable socio-economic factors affect and deplete water resources (El Fadel *et al.* 2010). The Lebanese population could endure water scarcity, depending on the projected increase in water demand and the degradation of water resources (MoE 2001). More than half of the inhabitants (59%) live near the coastal areas, only 8% of the country area (Atlas du Liban 2004) with a population density of about 420 inhabitants/km² (Sarraf 2010).

Population growth and rapid urbanization, in addition to climate change, increase the pollution of water chemically and microbiologically (Korfali & Davies 2003). As a result, a large part of surface water and groundwater become undrinkable (Naidoo & Olaniran 2013). Pollution of water resources with toxic trace elements, organic compounds, harmful microorganisms, and high salinity of drinking water could cause serious problems for human health. Hypertension diseases are due to high salinity levels in the body. In addition, high levels of copper can cause neurodegenerative diseases (Gaetke & Chow 2003; Vineis *et al.* 2011). Therefore, it is necessary to monitor and control the quality of drinking water regularly to avoid the risk of various diseases. Thus, the assessment of surface water depends on various physicochemical and biological constituents and their characteristics.

In Lebanon, there are 16 permanent rivers, 12 are coastal, while the remainder exist in the Bekaa valley (Nehme 2014). Four natural ponds (Al-Safsafa Stagnant, Al-Safsafa Tide, Al-Sayde, and Al-Asrawi known also as Ashtar), in addition to the Water Department reservoir, are located in Ras El-Ain. Based on water channels, these natural ponds irrigate more than 30 km^2 of cultivated land, which extends from Al-Mansouri city (10 km southern Ras El-Ain) to Al-Abassia city (8 km northern from Ras El-Ain) (Renan 1864). Lately, the water supply from these natural ponds has been extended to reach other nearby cities (Shaban & Hamzé 2018).

Water pollution in the Ras El-Ain ponds has become observed. It has increased in the past several decades due to population growth and significant climate change. Therefore, physical, chemical, and microbiological characteristics were affected by such factors. Sampling months were taken in April 2022, which is the end of the winter. Therefore, we have the highest water level, and the results of predicted existing contamination can have it with high precision. The generated dataset was processed using the PhreeQC software to determine the water quality and assess factors affecting the Ras El-Ain ponds, taking into account the origins of potential pollutants. PhreeQC software aimed to calculate saturation indices and determine the stability of minerals in the water samples. Specifically, we input the chemical composition of the water samples into the PhreeQC software and obtained saturation indices for different minerals. These results were then used to assess the potential for mineral precipitation or dissolution under different environmental conditions. All analyses were conducted in triplicate to ensure the accuracy and reproducibility of the results. The objective of this study is to comprehensively assess the water quality parameters of Ras El-Ain natural ponds, Tyr, Lebanon, by analyzing the concentration of various elements and pollutants present in the water, identifying potential sources of contamination, and evaluating the impact of these parameters on the overall water quality.

2. METHODOLOGY

To ensure a comprehensive assessment of the water quality parameters in Ras El-Ain natural ponds, we plan to use a combination of quantitative and qualitative methods. Water samples will be collected from multiple points within the natural ponds, and laboratory analysis will be conducted to measure the concentration of key water quality parameters including pH, turbidity, total dissolved solids (TDS), nitrates, phosphates, heavy metals, and fecal coliforms. This will be utilized to identify significant differences in water quality parameters between different locations. Finally, the concentration of each element will be compared to the limit values set by the Lebanese Standards Institution (LIBNOR) to provide an overall assessment of the water quality. As such, water samples from the five sources (Figure 1 and Table 1) were collected manually at a depth of 0.2–0.3 m. The samples were maintained in 2 L polyethylene plastic bottles for the physicochemical characterization (one bottle from each source), in addition to one sterile cup for the microbiological analysis. No detergent was used for the conservation or sterilization of the bottles, neither before nor after the water sampling. After that, all the labeled water

Figure 1 | Ras El-Ain natural ponds and water department.

Table 1 | The Ras El-Ain natural ponds and water department: designations and coordinates

Name	ID	Latitude	Longitude
Al-Safsafa Stagnant	SF-1	33°22′778	35°21′782
Al-Safsafa Tide	SF-2	33°22′769	35°21′771
Al-Sayde	SD	33°22′889	35°21′573
Al-Asrawi	SA	33°22′841	35°21′652
Water Department	MS	33°22′864	35°21′890

samples were preserved in a cooler until reaching the laboratory for analysis and testing. The microbiological characterization of the water was done within the first 24 h to eliminate any possible alteration in the results.

The microbiological water analysis is a method used in this paper to quantify the numbers of bacteria present and to allow for the recovery of microorganisms to identify them. The method of examination used was the plate count.

In this study, 20 factors were tested and presented to assess their impact, if available, on human health as well as the animals, and agricultural activities.

The water quality parameters were evaluated based on standard techniques used for surface water testing in Lebanon to render the analysis of the results possible. Several tests were conducted using the Lebanese University Laboratory apparatus, Hadath city, to obtain the following physical parameters: pH, electrical conductivity (EC 25), and TDS, using a digital pH meter and EC/TDS apparatus, respectively (LaMotte: HANNA instruments pH 211 Microprocessor).

As for the chemical characterization, several pieces of equipment were needed to cover all of the chemical parameters (major anions and cations) in the Lebanese University Laboratory. Cations concentrations were determined by Flame Atomic Absorption Spectroscopy (FAAS: RAYLEIGH-WFX 210) and covered the following elements Ca^{2+}, Cd^{2+}, Cu^{2+}, Fe^{2+}, Mg^{2+}, Pb^{2+}, and Zn^{2+}. FAAS spectroscopy is considered a method for identifying metals in solutions (Sharma & Tygi 2013). As for the anion concentrations, ionic chromatography (IC: Prominence UFLC – Shimadzu) was used to quantify the following anions such as Br^-, Cl^-, F^-, NO_2^-, NO_3^-, PO_4^{2-}, and SO_4^{2-}. Moreover, the incubation was done at 37 °C to observe the presence of total coliforms (after 24 h), and after 48 h to observe the presence of *Salmonella* and *Shigella*. However, at 44 °C, the existence of fecal coliforms was checked (especially *E. coli*). The results were done at the University of Balamand Laboratory, Al-Kurah City. The samples were not diluted. Moreover, 1 mL of pure water was added to the surface of the three culture mediums: plate count agar (PCA), salmonella shigella agar (SS), and MacConkey.

3. RESULTS AND DISCUSSION

The physicochemical analysis done in this study will allow the interrelation and assessment of the various natural and anthropogenic factors affecting the reservoir. The pH values for the water samples ranged from 6.6 to 7.6 (Table 2). These valued are

Table 2 | Physical tests results

	SF-1	SF-2	SD	SA	MS	LIBNOR norm values
pH	6.6	7.6	6.8	6.6	6.9	6.5–8.5
EC (μS/cm)	661	659	664	668	654	<1,500
TDS (mg/L)	350	333	332	334	344	<500

all within the acceptable limit referred to by LIBNOR (pH between 6.5 and 8.5). Based on the obtained pH values for the water samples, (near the normal value), the alkalinity was not tested.

Electrical conductivity (EC 25) is known for the measurement of the capacity of the water to carry electric current. The higher EC 25 is the more ions are available in the water (Hajjar 1997), and the percentage of TDS will increase (Gaetke & Chow 2003; Divya & Belagali 2012). The EC results of the selected samples were between 659 and 668 μS/cm (Table 2). All the measured values are within the LIBNOR norm (1,500 μS/cm) (LIBNOR 2010).

Concerning the TDS, it was seen that the obtained results did not exceed the limit specified by the LIBNOR norm (500 ppm) as seen in Table 2 (LIBNOR 2010).

As for the chemical characterization, the concentrations of the anions and cations gave a clear idea about possible sources of contamination if available. The concentration of calcium in the various samples varied between 100 and 122 mg/L (Table 3). The highest concentration value was observed at source SD (122 mg/L), even though it was still below the LIBNOR limit (equal to 200 mg/L) (LIBNOR 2010).

The high amount of copper harms human health, such as diarrheas and poisoning effects. Water generally offers only about 10% of the daily copper requirement (Shrimanker & Bhattarai 2022). The concentrations of copper in the water samples varied between 0.15 and 6 mg/L (Table 3). All the obtained results were below the acceptable limit set by LIBNOR (1 mg/L), except for the sample taken from the Al-Asrawi pond (SA) that mentioned a concentration of 6 mg/L. By assessing and characterizing the site location, it was seen that agricultural activities were developed all around the Ras El-Ain ponds, thus the uncontrolled use of fungicides and algicides was leading to the increase in the copper concentrations in Al-Asrawi pond (Drever 1997).

Moreover, the uncontrolled domestic discharge of garbage and sewage water was also observed near this pond (SA) which contributed to the increase in copper concentrations. From a toxicity point of view, a concentration of less than or equal to 0.1 mg/L inhibits the growth of aquatic plants (Mal *et al.* 2002).

A low iron level is not harmful to health, furthermore, excessive iron levels in water can lead to diabetes, hemochromatosis, stomach troubles, nausea, cause liver, pancreatic, and cardiac problems (Wessling-Resnick 2017). Concerning iron concentrations in the water samples, all the obtained results (Table 3) had values higher than the LIBNOR norm (0.3 mg/L) (LIBNOR 2010).

The variation in iron concentration is a result of a source polluted with iron. Most of these salts are insoluble, and they are either precipitated on different surfaces or absorbed. The existence of iron in natural water samples is due to rock and mineral decomposition, acidic mine drainage, uncontrolled landfill leaching, sewage effluents, and releases from iron processing industrial sectors (Korte *et al.* 2019).

Table 3 | Cations results

		SF-1	SF-2	SD	SA	MS	LIBNOR norm values
Cations (mg/L)	Calcium	120	108	122	100	116	200
	Cadmium	–	–	–	–	–	0.005
	Copper	0.23	0.230	0.15	6	0.53	1
	Iron	6.52	7.02	5.62	2.82	6.28	0.3
	Magnesium	24.5	22	24.3	20.4	23.7	50
	Lead	0.26	–	–	–	–	0.1
	Zinc	0.73	0.85	1.43	1.43	1.44	5

Because magnesium is a part of chlorophyll, it is a vital mineral for plants. Additionally, it is prevalent in mammalian tissues and essential for transporters, enzyme activity, and nucleic acid synthesis. Calcium, potassium, and sodium are affected by it. Hypomagnesemia is rather common, although different symptoms such as muscle pain, loss of sensation, and arrhythmia, only occur when there is a hypermagnesemia case (Yamaguchi *et al.* 2019). The concentrations of magnesium in the water samples ranged between 20.4 and 24.5 mg/L.

The highest concentration value (Table 3) observed in Al-Safsafa Stagnant water sample (SF-1) is still under the LIBNOR norm (50 mg/L) (LIBNOR 2010). This high value may be a result of being washed away from the rocks and eventually ending up in the natural ponds (Kosisek 2020).

Lead is among the most prevalent heavy metals, and due to its persistence in polluted areas and the intricacy of its biological toxicity mechanism, lead is particularly harmful to children and can induce mental retardation. Adults are also in danger from exposure to lead, especially for cardiovascular disease. These negative effects worsen as levels rise. However, the majority of lead concentrations in the environment are caused by human activity (Tiwari *et al.* 2013).

When analyzing the lead concentrations in all water samples, only one (SF-1) showed its existence with a value equal to 0.26 mg/L, which is above the LIBNOR norm (0.1 mg/L), while the rest did not depict any value (LIBNOR 2010). This high concentration is due to industrial and domestic corrosion processes in the old plumbing systems. In addition, water network pipes can increase the dissolution of lead into the water, and/or agricultural fungicides. However, the water remains favorable for irrigation (Chan *et al.* 2020).

Different mechanisms are used to transport zinc, which has the potential to be harmful, into the environment around it. Since of their predetermined character, propensity, toxicity, the propensity to accumulate in living organisms and contribute to the growth of the food chain, and much more, because they are non-degradable, waste dump contaminants are one of the most dangerous groupings among mining operations. Higher than allowed levels of zinc concentration in water are warning signs for health hazards (anemia, nausea, altered taste perception, increased risk of prostate cancer, and cause loss of smell) (Sankhla *et al.* 2019).

The concentrations of zinc in all the sources ranged between 0.73 and 1.44 mg/L (Table 3). The highest concentration is observed in the Water Department sample (MS), but it is still within the LIBNOR norm, which is 5 mg/L (LIBNOR 2010).

Because zinc occurs naturally in rock and soil, it may infiltrate into underground water. A variety of industrial processes generates trash with high concentrations of zinc, which can leak into the soil. This problem can be observed in houses having well water close to manufacturing plants. In addition, the water passing through galvanized pipes can have a high concentration of zinc (Noulas *et al.* 2018).

Eye inflammation was observed within the first 30 min of exposure at a bromine concentration of 0.1 mg/L. Specific nasal, eye, and throat discomfort occurred at doses of 0.2 mg/L or higher, with a decrease in focus response (Rae 2014).

The water samples from SF-1 and MS were free of bromine, while the other three samples showed a bromine concentration between 0.052 and 0.055 mg/L (Table 4). Although all obtained values were according to the LIBNOR standard, which is equal to 0.2 mg/L (LIBNOR 2010).

Natural reduction of bromate to bromide ions may occur in waters with low oxygen concentrations. The presence of bromate in drinking water may be associated with the reaction between bromide naturally present in drinking water and ozone (Greenwood & Ernshaw 2016).

Fish, reptiles, and amphibians are all poisoned by chloride. These types of animals, unlike humans and most domesticated animals absorb water straight into the bloodstream. Drinking or using water having small concentrations of chloramine does

Table 4 | Anions results

		SF-1	SF-2	SD	SA	MS	LIBNOR norm values
Anions (mg/L)	Brome	–	0.055	0.052	0.054	–	0.2
	Chloride	12.124	13.122	15.917	13.673	12.669	200
	Fluor	0.263	0.255	0.195	0.16	0.216	1
	Nitrite	0.665	–	0.022	0.121	0.271	1
	Nitrate	15.42	18.039	19.998	19.17	17.931	10
	Phosphate	–	–	–	–	–	1
	Sulfate	17.901	17.66	11.334	11.231	9.717	250

not have negative health consequences; on the contrary, it protects against waterborne illness epidemics. A reasonable amount of disinfection for drinking water can range from 1.0 to 4.0 mg/L (Shrimanker & Bhattarai 2022).

When determining the concentration of chloride in water, it is seen in Table 4 that all the tested sample values exceeded the recommended chloride norms (LIBNOR 2010). Chloride is highly mobile in soils and waters where it is present primarily as Cl^-. It is related to human-made origins. Discharges of both domestic and animal wastes contribute to the pollution of the water in chloride (Kincaid & Findlay 2009).

Exposure to high fluoride levels greater than the recommended norms can result in skeletal fluorosis, a disorder in which fluoride accumulates in the bones. All the tested water samples had results below 1 mg/L, which is the LIBNOR limits recommendation (Table 4; LIBNOR 2010). Fluoride-bearing groundwater, tectonic variables, ion exchange reactions, and the rate of degradation and absorption of underground pollutants all contribute to its availability in groundwater (Yadav *et al.* 2021).

The recognized dangerous effect of nitrate consumption is the result of nitrate transformation to nitrite. Anemia is a serious health complication of nitrate and nitrite exposure. The clinical appearance may be one of respiratory failure with oxygen deprivation, heart problems and circulatory arrest, and chronic central neurological consequences. The nitrate concentrations can be more harmful to newborns than nitrite since their bodies react differently to it (Skold *et al.* 2011).

The concentration of nitrites for all water samples (Table 4) did not exceed 1 mg/L as recommended by the LIBNOR limit. However, in all the water samples, the nitrate concentrations exceeded the LIBNOR limit (10 mg/L) (LIBNOR 2010). These high values are due to the excessive uncontrolled domestic waste spilled near the natural ponds, and most importantly, the untreated sewage disposed in the surrounding area (Ward *et al.* 2018).

Concerning the health impacts of sulfate in potable water, diarrhea is a result of drinking water with high amounts of sulfate (Darbi *et al.* 2003). The collected samples from the five locations had sulfate concentrations ranging from 9.717 to 17.901 mg/L, with the maximum values recorded in sources SF-1 and SF-2: 17.901 and 17.6 mg/L, respectively (Table 4). However, all sulfate concentration results were under the LIBNOR maximum permissible level (250 mg/L) (LIBNOR 2010).

The stratification of sulfates in the waters is certainly related to the worst habits biologically in the water ponds. It is derived from anthropogenic origins and activities. As the chloride, both domestic and animal waste contribute to the pollution of the water ponds in SO_4^{2-} (Long *et al.* 2021).

As for the microbiological characterization, the overall analysis summarized in Table 5 confirmed that the major sources of Ras El-Ain exceeded the limit recommended by LIBNOR (20 and 0 CFU/1 ml, respectively, for total coliform and *E. coli* and *Salmonella*). For source SF-2, it was noticed that the total coliform does not exist. Whereas, for the other three sources, their numbers are higher than the limit authorized by LIBNOR (LIBNOR 2010). However, these tests showed no signs of either *Salmonella* in any of the sources.

Therefore, the water from these sources is not suitable for drinking water, a treatment method should be considered, and it is all contaminated and polluted by bacteria. According to the findings of our investigation, the iron levels in the natural ponds were on average 0.3 mg/L higher than the LIBNOR-set limit threshold. This study raises the possibility that the natural ponds contain an iron source that could be harmful to both aquatic life and public health. Additionally, our study revealed that the nitrate concentration averaged 10 mg/L over the LIBNOR-set limit threshold. This research suggests that agricultural operations, which frequently contribute to high levels of nitrate in water bodies, may have an impact on the natural ponds. Additionally, the microbiological investigations found fecal coliforms in the natural ponds, which were in magnitude higher than the LIBNOR-set limit value. This study implies that sewage and other types of human waste may affect the natural ponds, which could provide a serious health danger to people and animals who come into touch with the water. The findings suggest that management measures are required for the natural ponds to address the causes of contamination and enhance the water quality. To contextualize the results,

Table 5 | Microbiology test results after 4 days

ID	Total coliforms limit 20 CFU/mL	*E. coli* limit 0 CFU/mL	*Salmonella* limit 0 CFU/mL
SF-1	>50	36 *E. coli*	–
SF-2	>50	–	–
SD	>50	86 *E. coli*	–
SA	>50	8 *E. coli*	–
MS	–	–	–

the use of both the analysis and the literature that has already been published in the area has supported the outcomes. For instance, Smith *et al.* (2018) carried out a comparable study on the water quality parameters of natural ponds in the neighboring Jezzine area in Lebanon. According to their findings, there were substantial concentrations of iron and nitrate as well as fecal coliforms and total coliforms. Similar to this, Massoud *et al.* (2016) examined the water quality of the Litani River, a significant water supply for the area, and discovered high nitrate and microbial pollution levels, indicating that water quality issues are a common issue in the area (Massoud *et al.* 2016). It allowed reaching more conclusive conclusions on the water quality of the natural ponds at Ras El-Ain, Tyr, Lebanon, and providing well-informed management and future research recommendations by comparing our findings to these and other pertinent field studies.

The use of PhreeQC, a geochemical modeling tool, gave an overall loop of the relationship between climate change and water pollution in the Ras El-Ain ponds. PhreeQC has been used to estimate how climate change could affect the water's geochemical behavior in the research area. The findings of the simulation indicated that the content of iron and nitrates in the water would rise with an increase in temperature and a decrease in precipitation. This result is in line with the body of literature that implies that by modifying the geochemical behavior of water sources, climate change can increase water pollution. Therefore, our work offers proof that the water quality in the Ras El-Ain ponds may be impacted by climate change, and more research is required to better understand and lessen this impact. When the physicochemical parameters are all coupled, an interpellation can be outreached. In this study, Piper, STABLER, and Schöeller Berkaloff diagrams are constructed to evaluate the variation in hydrochemical facies of water samples (Figures 2–4). The tendency of the cations for the

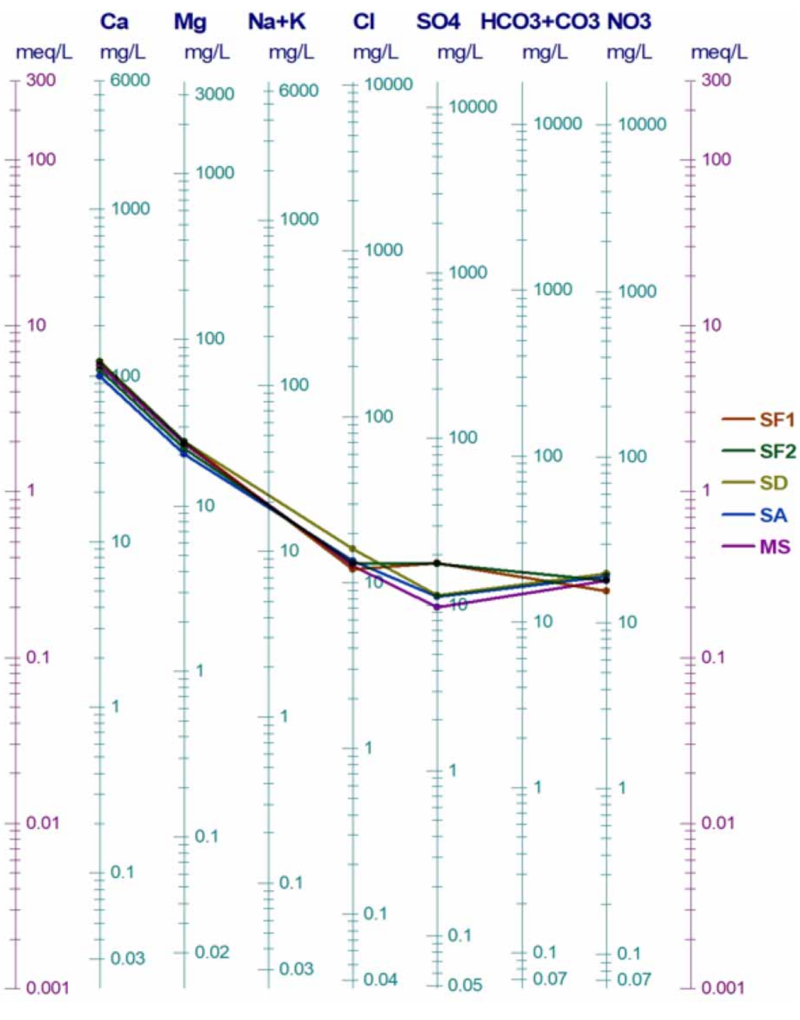

Figure 2 | Schöeller Berkaloff diagrams.

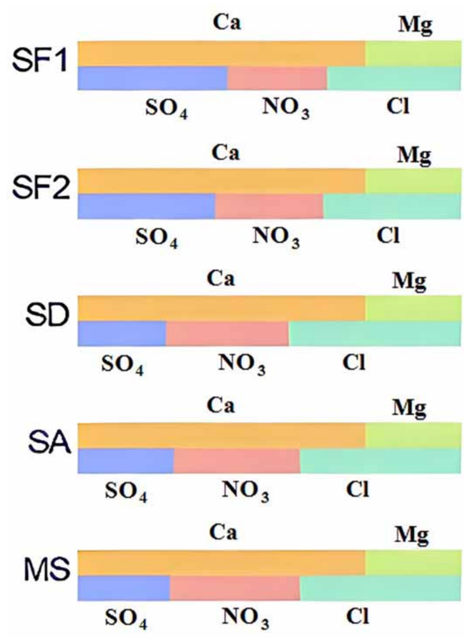

Figure 3 | Stabler diagram.

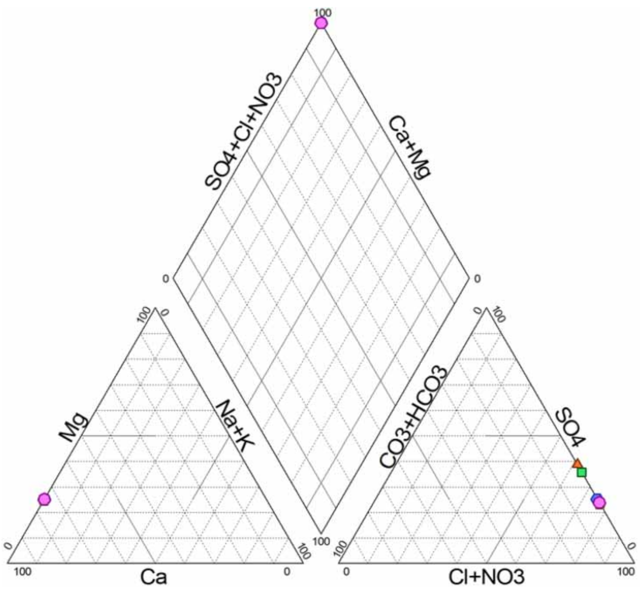

Figure 4 | Piper diagram.

raw water samples goes from high: Ca_2 Mg^{2+} > Na^+ > K^+ > SO_4^+ > $HCO_3 + CO_3 + NO_3$. As shown in Figure 2, calcium is the dominant cation in all water samples. The tendency of the anions, is to Cl^- and the dominant anion is chloride (Saba *et al.* 2019). The hydrochemical facies/water types are the same and influenced only by the geochemistry of the groundwater.

The Piper diagram also shows that sulfate (60%) and chloride (90%) are the most dominant ions without the presence of magnesium anion in all water samples. The Schöeller Berkaloff diagram highlights very similar trends between the studied water samples, in particular with different sulfate concentrations in the five water samples, confirming the results obtained by using Piper and Stabler diagrams (Saba *et al.* 2019). The piper diagram in Figure 2 indicates the ion predominance of the chemical species present; it was observed that the water in the five locations is hyper-sulfated. This is due to the geological formations in the area that are known to be sedimentary and predominantly affect the water (Nader 2014). The cation content is largely dominated by chloride.

4. CONCLUSION

The Ras El-Ain natural ponds were the subject of the study because they are crucial for Lebanon's water supply, notably for agricultural uses. The water sources' physicochemical characteristics, microbiological parameters, and heavy metal contents were examined and assessed. The findings showed that human activities had a negative impact on the natural ponds' water quality and that two of them As-Safsafa and Al-Asrawi have extremely high levels of heavy metal pollution.

The results indicate that a chemical study of the major ions and metals for each of the five affected locations is required to assure excellent water quality. In addition, it is advised that a more thorough investigation tying each characteristic and contaminant to its source be conducted to reduce certain contaminants in the natural ponds. The study has impacts on Lebanon's management of its water resources. The authors advise using wastewater treatment techniques at the source to raise the water's quality. It is suggested that residents be better informed and oriented about water pollution. In addition, treatment filters should be installed, and monitoring systems should be developed. Furthermore, excessive fertilizer use would be avoided, and that construction of landfill sites should be set aside far from water sources. Besides that, the environmental laws and regulations have to be enforced, polluter-pays principle have to be applied to all users, and that environmental indicators should be monitored and applied.

The study adds to our understanding of the variables affecting the water quality in Lebanon, especially in the Ras El-Ain natural ponds. The findings provide a basis for future work to improve water quality and management in the area. Some recommendations to take into account to improve the quality of the water in Ras El-Ain natural ponds:

- Improve the knowledge and the orientation of the inhabitants on the problem of water by integrating the essential aspects of the pollution of water and its sources.
- Educate residents about the installation of treatment filters to purify water by suggesting materials to dispose of solid and microbiological pollutants.
- Develop monitoring systems to periodically record water quality. These systems require both fixed and mobile monitor stations.
- Prevent excessive application of fertilizers to agricultural land.
- Dedicate well-defined landfill sites, which should be far away from water sources.
- Legislation and environmental laws should be enforced with a focus on pollution and water consumption.
- Government control should be applied over water resource areas, including rivers, springs, and lakes.
- Monitor and apply environmental impact studies to preserve the quality of water resources.
- Put in place laws regulating the physicochemical quality of domestic and industrial discharges (upstream treatment of pollution).
- Application of the polluter-pays principle to all users.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This is an observational study. The authors have confirmed that no ethical approval is required, and all the authors read and approved the final manuscript.

AUTHORS' CONTRIBUTIONS

All authors contributed to the study's conception and design. Material preparation, data collection, and some experiments were performed by M.D., and H.M. Other experiments and analyses were achieved by W.A. and M.S. M.K. wrote the first draft of the manuscript and all authors commented on previous versions of the manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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